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A MULTISCALE APPROACH FOR SEMI-AUTOMATIC COMPARISON ASSESSMENT OF LARGE SCALE FOREST MAPS

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ABSTRACT

In terms of climate change analysis, information on large area forest cover distribution becomes increasingly important for studying terrestrial carbon cycle changes and its human impacts. Within the FOREST DRAGON 1 project large-area forest growing stock volume maps of Northeast and Southeast China based on ERS-1/2 tandem coherence data have been generated. For the validation of the large-area forest stem volume maps, a special cross-comparison design mainly based on freely available Earth Observation products had to be developed in consequence of lacking extensive in situ measurements. The sampling design, based on the FAO *FRA2010 Sample Design* and the *Degree Confluence Project*, uses a 1 degree sampling grid with 10 x 10 km sample plots. A reasonable agreement above 70 % between the forest growing stock volume maps and the land cover datasets in terms of forest/ non-forest could be achieved for a total area of about 4.5 million km².

1. INTRODUCTION

The forests of Northeast China and Southeast China, which represent the most important wood supplies in China, have been ongoing constant pressure for several decades. The existing forest resources are not considered adequate for the needs of the Chinese economy and livelihood of the Chinese people. According to [1] the main problems are low total volume, low quality and sluggish growth of both, naturally growing forests and plantations. However, the current forest statistics in China differ significantly and indicate a need to monitor the forests status and their development on a regular basis with other methods [2]. Earth Observation (EO) provides a suitable tool which enables to consistently monitor forest cover and forest cover changes. It allows to identify environmental and in particular socio-economic impacts and to develop indicators for assessment approaches. This represents the background of the activities undertaken within Forest DRAGON 1 project and the ongoing follow-on project Forest DRAGON 2. During the Forest DRAGON 1 project (2004 – 2008), forest growing stock volume (GSV) (also named stem volume) maps were produced for Northeast (~1.5 Million km²) and Southeast China (~3 Million km²) at 50 m spatial resolution from ERS-1/2 tandem coherence data. A new classification approach, based on synergy between the ERS-1/2 tandem coherence and optical remote sensing products, in this case the MODIS Vegetation Continuous Fields dataset, has been developed for automatic and seasonal-adaptive retrieval of forest GSV. The procedure integrates the semi-empirical Interferometric Water Cloud Model and discriminates between four GSV classes (0-20, 20-50, 50-80 and > 80 m³/ha) and water [3]. This paper presents a method on how to assess the quality of the derived GSV maps by comparing against land cover datasets as a consequence of the lack of in-situ data of GSV. The approach considers scale effects, heterogeneous class descriptions of the specific reference data and problems in an accurate geolocation of these products.

2. STUDY AREA

The applied cross-comparison method was developed for the test regions of Daxinganling (Greater Hinggan Mountains; 53°8' N, 123°4' E; ~200 x 200 km) and Xiaoxinganling (Lesser Hinggan Mountains; 47°10' N, 128°53' E; ~300 x 300 km) in Northeast China (Fig. 1).

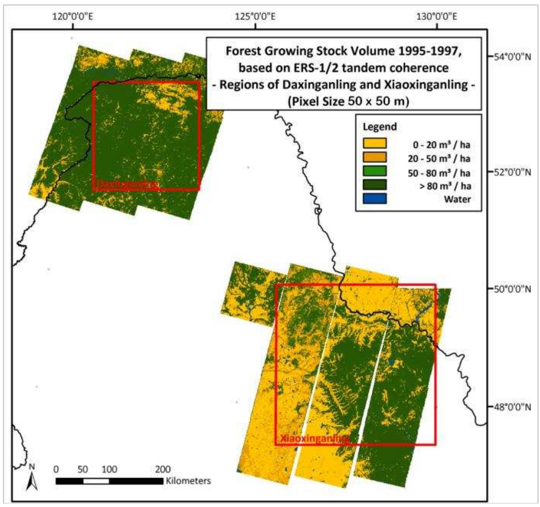

Figure 1. Location of the test regions Daxinganling and Xiaoxinganling and corresponding GSV maps

Daxinganling is characterised by gentle topography and needle-leafed forests dominated by larch trees. In general the GSV is of ~ 200 m³/ha. Xiaoxinganling is characterised by hilly terrain with an average slope of 10° and a low GSV, mostly below 200 m³/ha. The method has been applied to the GSV maps of entire Northeast and Southeast of China, covering in total an area of about 4.5 million km² (Fig. 2).

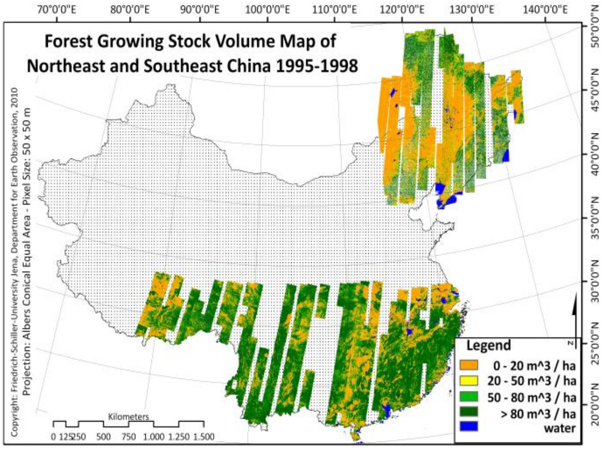

Figure 2. GSV maps for Northeast and Southeast China

3. REFERENCE DATASETS

For the comparison, several free available global land cover products with different scales and observation periods were considered (Tab.1). Furthermore, a re-classified version of the National Land Cover Database 2000 (NLCD) dataset could be used as additional reference.

Table 1. Available land cover datasets

Product	Sensor	Resolution	Year
UMD	AVHRR	1 x 1 km	1981 - 94
GLC2000	Spot	1 x 1 km	2000
VCF-MOD44	MODIS	0.5 x 0.5 km	2000 /05
GlobCover	MERIS	0.3 x 0.3 km	2004 - 06
NLCD	Landsat/ CBERS	0.05 x 0.05 km	1999

The AVHRR UMD land cover classification has been generated by the University of Maryland in 1998. Data from the AVHRR satellites acquired between 1981 and 1994 have been used to distinguish fourteen land cover classes, with an overall accuracy about 65 % [4]. The Global Land Cover 2000 (GLC2000) project is based on the VEGA 2000 dataset [5]. This dataset consists of 14 months (1 Nov. 1999 – 31 Dec. 2000) of daily 1-km resolution satellite data acquired over the entire globe by the VEGETATION instrument on-board the SPOT 4 satellite. Results of validation studies indicate an overall accuracy of around 68.6 % [6]. The MODIS Vegetation Continuous Field Tree Cover product (VCF TreeCover) contains proportional estimates for the vegetation cover type woody vegetation for the years 2000 and 2005 [7]. The product is derived from monthly composites of the 500 m MODIS sensor on-board NASA’s Terra satellite. All seven MODIS bands were used to calculate the percentage tree cover. The validation studies indicated for this product a standard error between 8 and 13 % for the classes < 10 % tree cover, 11-40 % percent tree cover, 41-60 % tree cover and above 60 % tree cover [8]. The continuous classification scheme depicts heterogeneous areas better than traditional discrete classification schemes. While traditional classification schemes indicate where land cover types are concentrated, the VCF Tree Cover product shows how much of forest cover exists on the land surface. GlobCover is an ESA initiative in cooperation with JRC, EEA, FAO, UNEP, GOFC-GOLD and IGBP. Based on ENVISAT MERIS 300 m data global composites and land cover maps have been produced. The GlobCover service has been demonstrated over a period of 19 month (Dec. 2004 – Jun. 2006) for which a set of MERIS Full Resolution (FR) composites (bi-monthly and annual) and a Global Land Cover map with an accuracy level about 67 % have been produced [9]. The NLCD product was produced by the Chinese Academy of Sciences (CAS) by the visual interpretation and digitization of satellite images including georeferenced and orthorectified Landsat TM and CBERS scenes from 1999 and 2000. A hierarchical classification system was applied and showed an overall accuracy greater than 92 % for the 25 sub-classes [10]. Thus, the NLCD product is very well qualified as reference for the comparison method.

4. COMPARISON METHOD

In addition to the advantages provided by satellite products, certain limitations exist that need to be objectively quantified to assess accuracy and understand the full potential and limits of Earth Observation. A comparison with global land cover dataset faces various challenges, including the high amount of mixed pixels at the coarser scale spatial resolution, the heterogeneous class descriptions and problems in an accurate geolocation of the products [11].

In terms of implementing a robust accuracy assessment of different land cover datasets, we oriented ourselves to the scientific state of the art, published in a ‘best practice’ document 2006 [12]. Reference [13] distinguished four approaches for a quantitative estimation of the accuracies of land cover classifications: confidence values of the classifier, map comparison, cross-validation with training datasets and the use of a robust spatial sampling design including ground reference information. Due to the lack of training datasets, ground references and robust classifiers, the comparison technique was applied to assess the quality of the retrieved GSV classes.

As mentioned above, comparing different thematic maps such as the ERS-1/2 GSV map and a coarse resolution land cover product implies having to face a number of issues related to spatial resolution and nomenclature. The varying amount of thematic classes, different methods and algorithm used for the class assignation and various spatial scales of the maps lead to significant problems on how to set up the comparison in a possible manner [14]. Different approaches can be utilized for a comparative assessment of the GSV maps with the different coarser resolution land cover datasets.

In the first approach, the cross-comparison assessment is conducted at single pixel-level of the GSV map. The affiliation of each of the GSV map pixel to the coarser resolution land cover map is analysed by using a geospatial function. This allows an exact comparison of the high resolution GSV dataset with the coarser resolution land cover datasets without losing any thematic or spatial resolution. Problems occur when comparing the GSV map with ambiguous land cover classes, such as the *GlobCover* class 110 '*Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)*', because an agreement of the ambiguous land cover class with several GSV classes is possible.

The second approach is conducted at the level of the coarse resolution single pixel of the land cover products. The distribution of the different GSV classes for each land cover class is analysed. Hence, the comparison of the GSV classes with the fuzzy described land cover classes (e.g. *GlobCover* class 110: '*Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)*') is possible. The method is not fully robust, because of data gaps within the GSV map caused by the poor quality of the interferometric signal in steep mountainous terrain and due to gaps in the SAR data coverage, which prohibit the full coverage of the land cover pixels. Consequently, the analysed percentage distribution of the GSV classes is not complete. Hence, the results have to be considered as not clearly interpretable.

The alternative method to aggregate the GSV pixel to achieve the pixel resolution of the land cover product, implicates a high potential error [15, 16]. Furthermore, it is not possible to transfer the comparison assessment results of the aggregated GSV product to the original, high resolution GSV product. Due to the high uncertainty of the results, this approach was not considered.

We used instead the first approach and developed an intersection method to solve the addressed problems by masking out areas characterized by ambiguous land cover information. However, the resulting information deficit in very heterogeneous areas and the transition regions between the classes affected no more than 3 % of the sample area. Therefore, the initial step of the developed comparison method comprised a multi-scale intersection process. To enable a robust comparison method, it was necessary to relate each pixel of a finer scale product unambiguously to a class of the coarser scale products. The comparison was carried out at the highest possible resolution, i.e. 50 × 50 m². For each pixel in the high resolution product it was analysed, which was the corresponding class information in respective coarser scale land cover products. In the case of the occurrence of at least 2 classes, the relevant area of the high resolution product was masked out (Fig. 3).

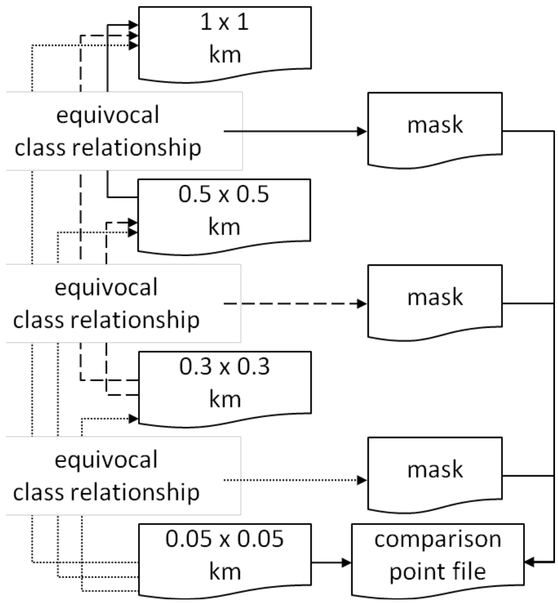

Figure 3. The multi-scale intersection concept with the stepwise check of coarser scale class information and the resulting masks

Due to the clear class assignment for each pixel, this allows a robust thematic comparison of the high resolution datasets with all of the coarser resolution land cover datasets.

4.1. Sample design

The applied sampling design for the comparison has been based on the FAO FRA2010 Sampling Design [17] and the Degree Confluence Project [18]. Latitude and longitude intersects (confluence points) were used to create a systematic sampling grid/design with an area of 10 km x 10 km covered by each sample site (Fig. 4).

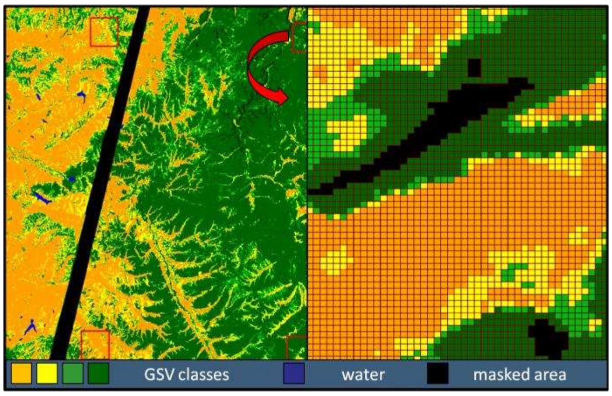

Figure 4. Example of Sample Plots with confluence centre points for Northeast China. The red squares on the picture on the left indicate sample plots. The picture on the right shows a blow-up of a sample plot.

4.2. Legend harmonization

Due to the fact that the developed comparison method is not fully robust when comparing the fuzzy described land cover classes and the GSV classes, the comparative assessment of the GSV maps with the different land cover classes has so far been conducted on the basis of forest and non-forest classes only. For this purpose, a legend harmonization of the used land cover products was necessary.

In the first step, the GSV classes were separated into forest and non-forest. According to the FAO Forest Resources Assessment 2000, China's average GSV amount to 52 m^3/ha [19]. Hence, the GSV map classes 3 (50-80 m^3/ha) and 4 (> 80 m^3/ha) have been aggregated as forest, whereas the other three classes have been defined as non-forest. Although this definition of forest/non-forest is questionable, it reflects an official value that can be used as reference. For the reclassification of the land cover products into forest and non-forest, the concept of the Land Cover Classification System (LCCS) for legend harmonization, suggested by the United Nations Environment Programme (UNEP) and FAO, was implemented [11, 20]. During this process, the respective class descriptions were analyzed and combined. Due to the fuzzy class description, such as the *GlobCover* class 110 (*Mosaic forest or shrubland (50-70%) / grassland (20-50%)*), sometimes it was difficult to get biunique assignments. Thus, before the reclassification process, a cross comparison between the land cover products was realized. The resulting class distribution charts showing the amount of conformable samples for each class, whereby the symbol size represents the proportion of samples for the respective corresponding classes (Fig. 5).

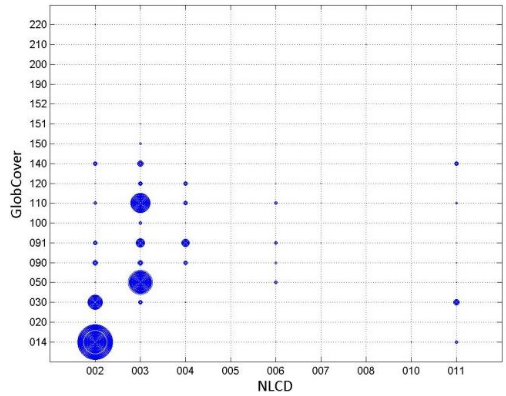

Figure 5. Land cover cross comparison in Xiaoxingaling for the GlobCover product and the NLCD dataset considered as reference

For example the largest agreement of the described fuzzy *GlobCover* class 110 ('*Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)*') is obtained for the NLCD class 3 (*mixed forest > 30 %*). Accordingly, during the reclassification process, this class is allocated to the forest class. In this way, such charts give a decision support especially for the classes with complex or ambiguous class name description. Based on this information and the LCCS legend harmonization concept, the reclassification were established (Tab. 2).

Table 2. Reclassification based on the legend harmonization concept

	Non-Forest [Classes]	Forest [Classes]	Class Description
GSV map	1, 2, 5	3, 4	[3]
GlobCover	11 - 40, 130 - 220	50 - 120	[9]
GLC2000	11 - 22	1 - 10	[5]
UMD	0, 8 - 13	1 - 7	[4]
VCF2000	<15 % Canopy Cover	≥15 % Canopy Cover	[13]
NLCD	1, 2, 7 - 12	3, 4, 5, 6	[10]

4.3. Accuracy Metrics

The descriptive statistic analysis used a 2D binning for the comparative assessment and results in a correlation (difference/error) matrix. Based on this matrix, the basic accuracy metrics percentage of cases correctly allocated (***oa***) and the cohen´s kappa coefficient (***k***) were derived (Eqs. 1, 2) [21].

	Product 1 Class a	b	Σ
Product 2 Class a	n_{aa}	n_{ab}	n_{a+}
b	n_{ba}	n_{bb}	n_{b+}
Σ	n_{+a}	n_{+b}	n

$$oa = \frac{\sum_{i=1}^{q} n_{ii}}{n} \quad (1)$$

$$kappa = \frac{n\sum_{i=1}^{q} n_{ii} - \sum_{i=1}^{q} n_{i+}n_{+i}}{n^2 - \sum_{i=1}^{q} n_{i+}n_{+i}} \quad (2)$$

q = number of classes
n = total data samples
n_{ii} = amount of agreeing samples
n_{i+} = value of row totals
n_{+i} = value of column totals

The metric ***oa*** describes the *overall agreement* of two products for the whole map. In the case of one dominant class the ***oa*** is largely affected by the agreement of this class. Thus, high overall agreement con occur even if the agreement of the second class is very low. In consideration of this, we also introduce a normalized class distance ***p*** (*occurrence distance*) between the classes forest and non-forest which were used for a class specific estimation of the overall map agreement (Eq. 3).

$$p = \frac{n_{aa}n_{bb}}{\left(\frac{\sum_{i=1}^{q} n_{ii}}{2}\right)^2} \quad (3)$$

4. RESULTS

The cross-comparison of the GSV map with the continuous MODIS tree cover product (MOD44B) shows a very strong correlation of the distribution of the different GSV classes with the respective tree cover classes. The aggregated GSV forest class exhibits a coefficient of determination of 0.96, which indicates the plausibility of the GSV classes (Fig 6). However, a reliable statement of the accuracy of the specific forest growing stock volume is not possible.

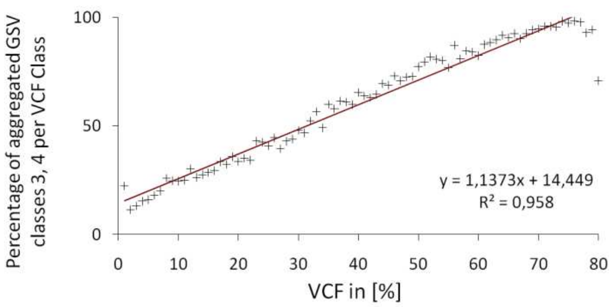

Figure 6. Correlation between the aggregated GSV class and the continuous MODIS tree cover classes

For the test areas Xiaoxingaling and Daxingaling, the GSV product features a very good agreement with all land cover products, though, due to the moderate thematic accuracy of the coarser scale LC products, a great uncertainty remains (Tab. 3). The comparison of the derived forest / non-forest maps with the NLCD dataset, here considered as primary reference product, showed an overall agreement of 80 % for the aggregated GSV map, thus indicating the high quality of the forest / non-forest information contained in the GSV maps from ERS-1/2.

Table 3. Overall agreement between the GSV map and the LC products for the test areas based on aggregated forest/ non-forest classes

	OA	*Kappa Coefficient*
GSV vs. NLCD	0.80	0.60
GSV vs. GlobCover	0.81	0.64
GSV vs. VCF (>15% CC)	0.87	0.75
GSV vs. GLC2000	0.80	0.59
GSV vs. AVHRR LCC	0.65	0.41

These results gave us confidence that the proposed approach for assessing the quality of the ERS-1/2 GSV maps can be applied to provide overall figures for the entire Northeast and Southeast of China. Tab. 4 and 5 show that the GSV product for Northeast and Southeast China featured a reasonable agreement with all LC products.

Table 4. Overall agreement between the GSV map and the LC products for Northeast China based on aggregated forest/ non-forest classes

	OA	*Kappa Coefficient*
GSV vs. NLCD	0.79	0.55
GSV vs. GlobCover	0.74	0.49
GSV vs. VCF (>15% CC)	0.78	0.52
GSV vs. GLC2000	0.79	0.59
GSV vs. AVHRR LCC	0.77	0.51

Table 5. Overall agreement between the GSV map and the LC products for Southeast China based on aggregated forest/ non-forest classes

	OA	*Kappa Coefficient*
GSV vs. NLCD	0.68	0.33
GSV vs. GlobCover	0.74	0.43
GSV vs. VCF (>15% CC)	0.80	0.52
GSV vs. GLC2000	0.68	0.33
GSV vs. AVHRR LCC	0.68	0.32

Since the freely available land cover products present an overall accuracy as best of only 65 % for the forest class for whole China [22], the forest / non-forest information derived from the GSV maps are of extreme appeal because they combine high resolution and large coverage for the mid-1990s for China. Moreover, the thematic information of the GSV map can be found within the LC products (especially in the VCF product), which demonstrates the plausibility of the information about the forest growing stock volume. Accordingly, in areas where the GSV map and the LC products agree, the high resolution GSV product can provide information about the distribution of forest and the respective forest growing stock volume underneath the single coarse resolution LC pixel.

5. CONCLUSIONS

The results of the cross-comparison of the GSV maps with existing land cover products highlight the high quality of the retrieved forest growing stock volume using the algorithm presented in [2]. It was shown that the method here presented provides appropriate information about the plausibility and quality of the produced forest cover maps. However, due to the unavailability of large-scale datasets of in-situ measurements, a pure accuracy assessment of the growing stock volume is not possible.

In consideration of factors that can affect accuracy, such as registration and legend conversion problems, the developed semi-automatic approach is completely transferable to other large-area investigation areas and fully adaptable to similar existing land cover data. Since similar global data sets will be available in the future (e.g. within the framework of ESA Sentinel programme), the developed approach is well suitable for scale and thematic independent accuracy assessment applications.

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